[redacted]

NASA TT F-8246

SOURCE OF PLASMA FOR HIGH VACUUM

By B. P. Kononov and K. A. Sarkasyan

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON February 1962

DRAFT TRANSLATION

SOURCE OF PLASMA FOR HIGH VACUUM

Zhurnal Tekhnicheskoy Fiziki
(Journal of Technical Physics)
Vol. 31, No. 11, pp 1294-7
1961.

By B.P. Kononov
K.A. Sarkasyan

10458

(Summary) The authors describe an experimental device for obtaining plasma by way of mixing electron and ion beams in a vacuum system with a pressure drop. In the report, plasma was obtained with a density of 10^{12} -- 10^{13} cm^{-3} in a vessel pumped out to a pressure of $2 \cdot 10^{-5}$ mm of merc col.

In the conduct of many experimental studies, it is necessary to have a plasma at sufficiently low pressure of neutral gas. The known ionization methods (Pening discharge, high frequency discharge and others (Refs. 1-4)) do not furnish the possibility of obtaining a plasma with a sufficiently high density at gas pressure of the order of 10^{-5} mm of merc. col. One of the possible ways of solving the problem is the use of "plasma beams". However the use of such injectors is associated in a number of cases with difficulties owing to fouling of the plasma by the electrodes' material from the neutral gas which follows the plasma, as well as other reasons.

Of great interest for obtaining plasma is the method of diffusion in a magnetic field with the use of a vacuum system with a pressure drop. For example, such a type of plasma source was used for filling a magnetic trap (Ref. 5) and during the conduct of experiments with plasma beams (Refs. 6, 7).

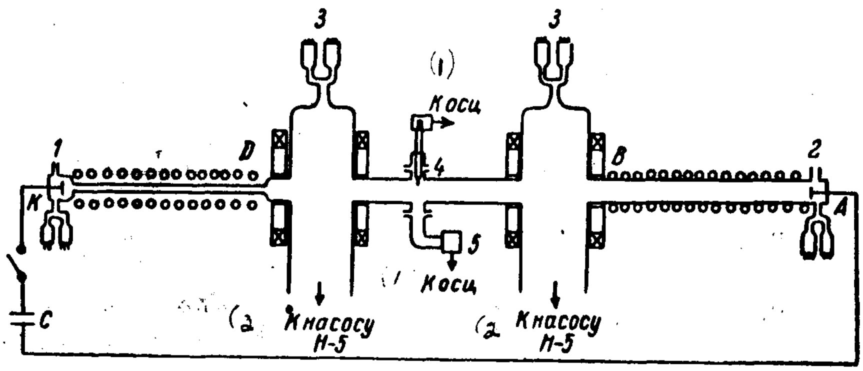

Figure 1. General view of test device.
1 - admission of gas, p = $4 \cdot 10^{-2}$ mm merc. col;
2 - admission of gas, p = 10^{-3} mm of merc. col;
3 - p = 2 x 10^{-5} mm of merc. col;
4 - high frequency probe;
5 - MH5
Captions within figure - 1. to oscillograph; 2 - to H-5 pump

One of the authors suggested a layout for the device for obtaining plasma in a vacuum system with a pressure drop by way of mixing electron and ion beams. In Figure 1, we have depicted schematically a device on which we conducted experimental investigations. Along the tube AD (d = 4 cm, l= 1.5 m) and KD (d = 1 cm, l= 1.5 m), a pressure drop was maintained by way of continuous admission and pumping out of gas (air). With the aid of a system of coils, we generated a longitudinal magnetic field with a force of 200 - 1000 oersteds. During the feeding of voltage from a capacitor to the electrodes, a discharge was developed in a small space adjacent to the cathode K. The electrons being emitted from the area of the cathode moved in the direction of the anode A and produce an ionization of the gas in the anode area. The ions, having formed in the anode tube, under the effect of the electrical field, move toward the electrons. At the moment of compensation by a flow of ions of the spatial charge of electrons, the discharge current increases sharply, and the discharge capacitor C quickly discharges.

At this moment, the density of the plasma, having formed in the area of the high vacuum, attains a maximum value. In Figure 2 we have adduced oscillograms, illustrating the processes that have transpired. The plasma density was measured with a single high frequency probe (sonde) (Reference 8).

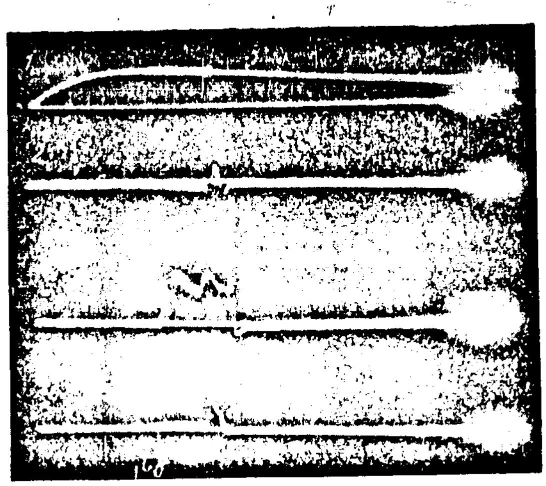

Figure 2. Oscillograms of the processes during the discharge in high vacuum.
1 - magnetic field; 2 - signal from the probe, density 10^{12} cm^{-3}; 3 - signal from the probe, density 10^9 cm^{-3}; 4 - discharge current; t_o - beginning of the discharge. Duration of scanning = 2.5 millisecs.

Two generators were used with a frequency of 290 and 10,000 mc, which permitted us to record the moment of the passage of the plasma density through the value 10^9 cm^{-3} and 10^{12} cm^{-3}. In conformity with the theory, the signal from the probe, recording a density of 10^{12} cm^{-3}, consists of two peaks $(\omega_H > \omega)$. The signal from the probe, recording 10^9 cm^{-3}, has a rectangular form $(\omega_H < \omega)$, and the leading and trailing edges correspond to the moment of density's passage through the value 10^9 cm^{-3}.

From the oscillograms adduced, it is apparent that the maximum density value in the discharge exceeds 10^{12} cm^{-3}.

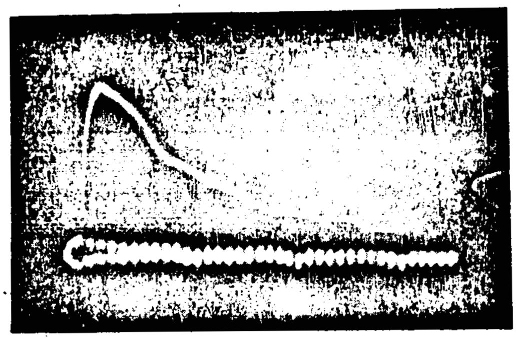

Figure 3. Oscillogram showing the pressure rise after discharge. Time markers every 2 millisecs.

In the study, there was conducted a measurement of gas pressure after cessation of the discharge. Pressure was measured with a magnetic gas discharge manometer, type MH-5, from which a signal was fed to the oscillograph. For reducing the entry of plasma into the manometer, it was connected to a vacuum device through a curved metal tube (Figure 1). The admitting capacity of the connecting tube was selected to be greater than that of the central part of the discharge tube. The gas discharge manometer has an operational inertness (Reference 9). We measured the time of the establishment of the discharge in the manometer at rapid change in the voltage in it from 1 to 3 kv, which was accomplished by a special circuit with the use of a thyratron. At pressure of $2 \cdot 10^{-5}$ mm of merc. col., this time amounted to 200 microsecs. The oscillogram of the signal from the manometer at the time of discharge is adduced in Figure 3. The signal's trailing edge is determined by the pumping-out rate. Since the duration of the trailing edge is much greater than the time constant of the manometer, the increase in the gas pressure can be found by extrapolating the trailing edge up to the time moment at the beginning of the discharge. The measurements conducted showed that the gas pressure increases from $2 \cdot 10^{-5}$ up to $(1 - 2) \cdot 10^{-4}$ mm of merc. col., which can be explained by the recombination of the plasma. Additional measurements were carried out at weaker discharges, when the plasma's maximum density was less than 10^{12} cm^{-3}. In this case, we noted a slight (sic) increase in pressure by 20 - 50%.

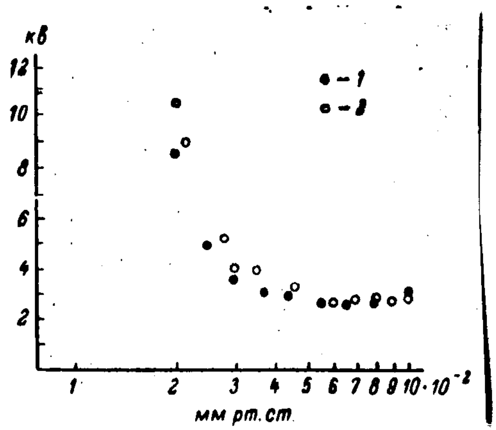

Figure 4. Dependence of voltage of discharge's firing upon pressure in area of the cathode.
1 - with pressure drop
2 - without pressure drop
Caption under x-axis: mm of merc. col.

In the study, we investigated in more detail the features of the phenomena transpiring in the cathode and anode parts of the discharge. The voltage of the discharge's firing was determined chiefly by the conditions in the cathode area and depends but little on the presence of a pressure drop. This was verified by measuring the firing voltage both with and without a pressure drop. Measurements were conducted for a stationary gas discharge during delivery (to the cathode) of a constant controlled voltage without a magnetic field. The dependence derived is adduced in Figure 4. Pressure was changed by changing the amount of gas being admitted.

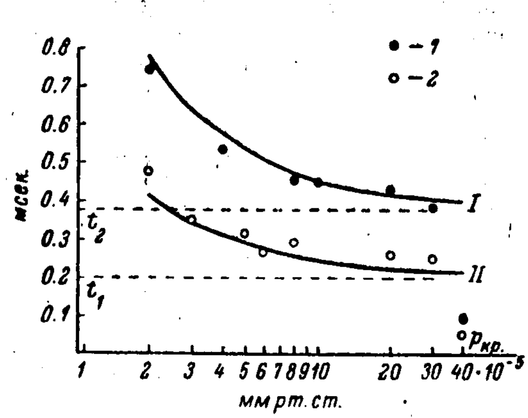

Figure 5. Dependence of delay of current upon pressure for two voltage values in the discharge capacitor. 1 and 2 - experimental points; solid curves = calculated. I = 11.5 kv, II = 15 kv. Captions within Figure 5 - To left of y-axis: millisecs; above x-axis: p_{crit}; under x-axis: mm of merc. col.

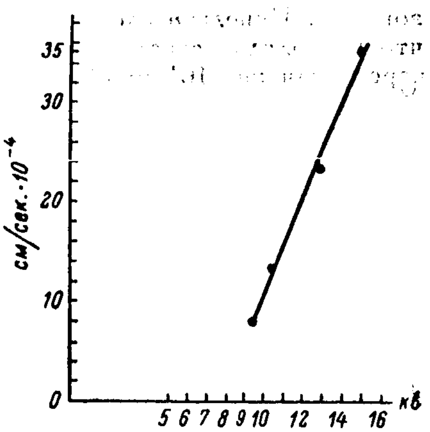

Figure 6. Dependence of ions' velocity on voltage in a discharge-type capacitor.
Caption to left of y-axis: cm/sec · 10^{-4}
Caption to x-axis: kv

As is evident from the oscillograms adduced in Figure 2, between the beginning of the discharge and the time when the discharge current attains the maximum value, there is a delay which is explained in that the compensation of the spatial charge of the electron beam and the increase in current occur only after the ions, moving from the anode part of the discharge, have reached the cathode tube. As the measurements conducted have shown, the delay in the current's development depends upon the voltage to which the discharge-type capacitor is charged, as well as on the pressure drop in the anode tube. In Figure 5, we have shown the experimentally-obtained dependence of current delay upon pressure in the area of high vacuum for two voltage values in the discharge-type capacitor. Pressure was changed by a change in the amount of gas being admitted. As is evident in Figure 5, at pressure in the central tube amounting to $p_{crit} = 4 \cdot 10^{-4}$ mm of mer. col., the delay drops abruptly to zero. This signifies that the number of ions being formed by an electron beam at the pressure $p \gg p_{crit}$ is adequate for the compensation of the spatial charge. At $p < p_{crit}$, the delay in the current's development will be fixed by the time necessary for the ions to traverse the distance from the area in the anode tube where $p = p_{crit}$, to the cathode tube. It is easy to compute that this equals:

$$t = \frac{12 d^3 p_{\text{кр.}}}{S_H p v} + \frac{l_0}{v},$$

where d = the diameter of the anode tube (4cm); S_H = the pumping-out rate (200 liters per sec); p = high vacuum pressure; l_0 = length of the tube (70 cm) where the high vacuum is present; v = average velocity of ions' motion.

From the experimentally determined time values for t_1 and t_2 (Figure

X63-10458

5), one can determine the velocity of ions' motion for both cases: $v_1 = 3.5 \cdot 10^5$ cm/sec, $v_2 = 1.8 \cdot 10^5$ cm/sec. In Figure 5, we have adduced curves constructed on the basis of Eq. (1) for the values derived for v. In Figure 6, we have indicated the velocity of ions' motion, measured for several values of voltages in the discharge-type capacitor.

In conclusion, the authors express gratitude to Prof. M. S. Rabinovich for his interest in the report and for his valuable comments.

REFERENCES

1. Reynold, P. and Skarsgard, N. M. CERN, 59-19, 1958.
2. Reykhrudel', E. M. et al. Zhurnal Tekhnicheskoy Fiziki, Vol. 22, No. 12, pp 1945-66, 1952.
3. Reykhrudel', G. V. and Smirnitskaya, G. V. Izvestiya VUZ, Radiofizika, I, No. 2, pp 36-44, 1958.
4. Glazov, A. A. and Novikov, D. A. Zhurnal Tekhnicheskoy Fiziki, Vo. 28, No. 10, p 2295-2301, 1958.
5. Yushmanov, Ye. Ye. Collection "Physics of Plasma", IV, USSR Academy of Sciences Publishing House, Moscow, 1959.
6. Garrison, E. R. and Dawton, R. H. I Electr. and Control, 5, No. 1, 29-32, 1958.
7. Garrison, E. R. Phil. Mag., 3, No. 35, 1318-1325, 1958.
8. Kononov, B. P., Rukhadze, A. A., and Solodukhov, G. V. Zhurnal Tekhnicheskoy Fiziki, Vol. 31, No. 5, p 565, 1961.
9. Borodkin, A. S. Zhurnal Tekhnicheskoy Fiziki, Vol. 30, No. 3, p 359-64, 1960.